Study of abandoned uranium mining impacts on private lands surrounding the North Cave Hills, Custer National Forest, South Dakota

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Abstract. During the late 1950s and early 1960s substantial prospecting and mining of uranium resources occurred in western South Dakota. As a result of these historic mining activities, degradation of both land and water resources occurred through the migration of the contaminated and hazardous materials (including As, Mo, Ra^{226}, Th, U, V) by water and wind erosion. Through US-EPA CERCLA funding, a Joint Venture Agreement between the USDA-Forest Service Northern Region Office and the South Dakota School of Mines and Technology (SDSM&T) has been established to evaluate impacts to soil, water, and air resources from the migration of contaminated material on or adjacent to lands administered by the USFS Sioux Ranger District of the Custer National Forest. Historical environmental impacts from regional historical uranium mining operations, the current knowledge regarding on-and off-site contamination, and results from the surface water portion of the overall study are presented. The surface water results suggest widespread heavy metal and radionuclide contamination exists within the Petes Creek drainage located on private lands east of the North Cave Hills complex. The source of contamination appears to be from both controlled and uncontrolled sediment flows from the Riley Pass (Bluff B) minesite. Total arsenic and uranium concentrations found within the Petes Creek drainage range from 2.163 and 1.124 mg L^{-1} (65 and 91x established background), respectively, within the upper reaches of Petes Creek, to 0.085 and 0.067 mg L^{-1} (both 4x background), respectively, prior to discharge into Crooked Creek. Concentrations of all contaminants were below 3x established background within Crooked Creek approximately 2 miles downstream of the Petes Creek confluence.

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Introduction

This report has been prepared as part of the North Cave Hills Area Abandoned Uranium Mines Impact Investigation that is being conducted under a Joint Venture agreement between the United States Department of Agriculture-Forest Service (Forest Service) and the South Dakota School of Mines and Technology (SDSM&T), and a subcontract with Ogala Lakota College (OLC). Funding for this on-going study has been provided through US-EPA CERCLA. This report describes both the field and laboratory methods used to collect data for the evaluation of potential environmental impact of abandoned uranium mining and exploration sites in the North Cave Hills, Harding County, South Dakota. Specifically, this report addresses surface water results from the "watershed" study used to assess off-site migration of mining spoils and associated metals and radionuclides from the North Cave Hills region of USFS administered lands. The project is on-going and results from other project phases have not been completed by the date of this report submission (August 15, 2006). Findings from other aspects of the overall study will be addressed within a separate final project report to the Forest Service by December 31, 2006. The final project report will be accessible via the project website www.cavehills.org. The final report will include additional findings and discussions pertaining to other overall project phases, including:

- Off-site migration of sediment spoils and associated metals and radionuclides from the North Cave Hills region of USFS administered lands into potentially impacted drainages;
- Off-site migration of airborne dust particulates and associated metals and radionuclides by wind erosion of mining spoils from USFS administered lands onto adjacent and regional private lands;
- Potential contamination to the regional ground water supply by introduction of metals and radionuclides into regional aquifers that provide drinking water to local residents and livestock.

Within this report, we have provided detailed discussions regarding background information including site geology, hydrology, and other relevant site characteristics, and discussion of known historical mining activities that occurred in the North Cave Hills regions.

Background Information

The North Cave Hills area is part of the Sioux Ranger District, Custer National Forest, Region 1 of the USFS. The complex is located approximately 25 miles north of Buffalo, South Dakota (Harding County Seat) and 150 miles north-northwest of Rapid City, South Dakota. Ludlow**,** South Dakota, is the closest municipality located 5 miles due east (Figure 1).

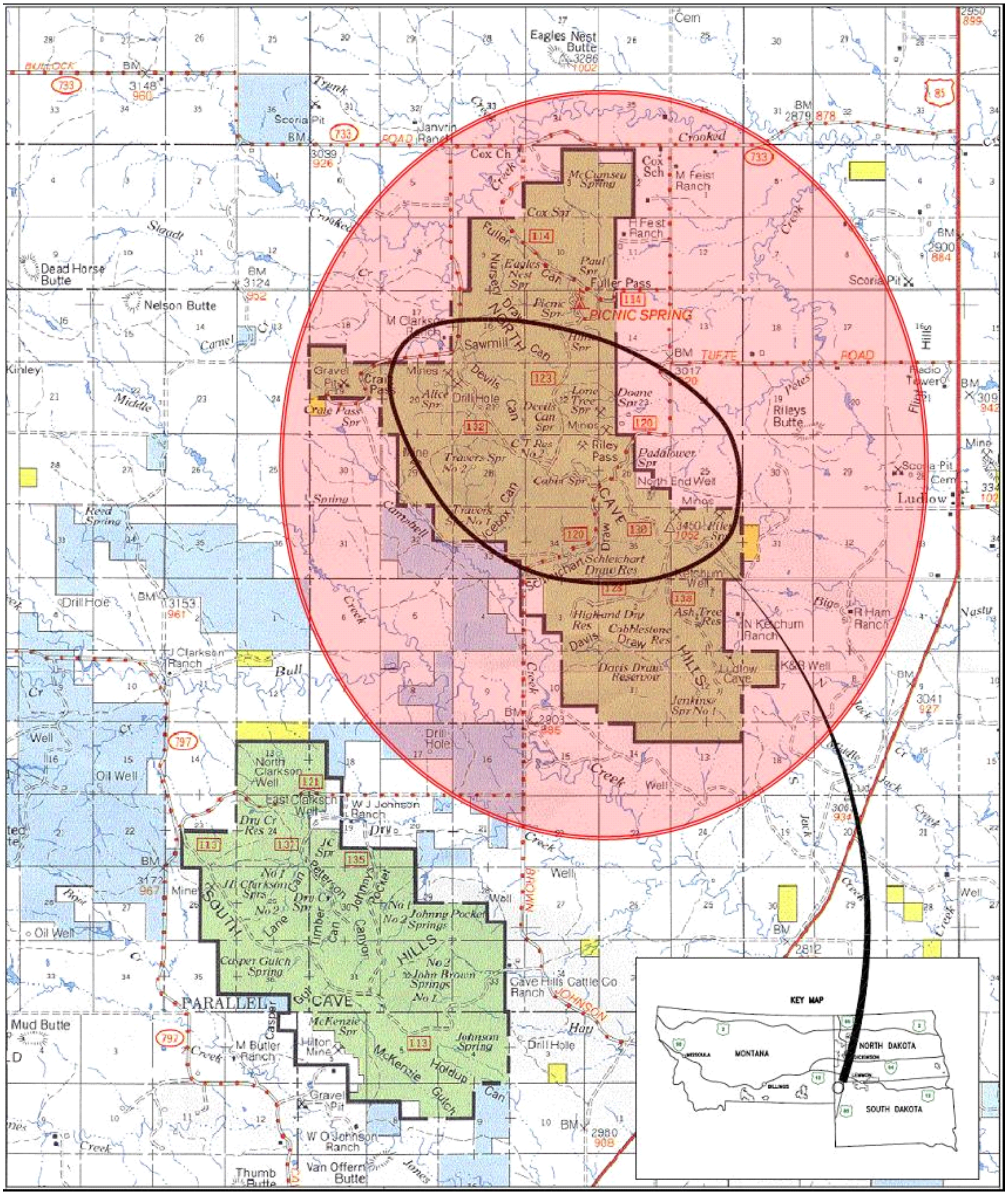

Figure 1. Study location map of the North Cave Hills; black oval marks the abandoned Riley Pass uranium mines; red, shaded oval represents the area covered by this investigation.

Geomorphology

The North Cave Hills rise about 400 feet above the surrounding plains to an altitude of approximately 3,400 feet. They are characterized by steep-sided and generally flat-topped, forested buttes rimmed by 60-150 feet high sandstone cliffs. Below the cliffs, softer sedimentary rocks including shale, siltstone, coal and loosely cemented sandstone form steep, grass-covered slopes. From a geomorphic perspective these slopes contain evidence of geologically rapid retreat. Erosion of the softer sedimentary rocks below the sandstone cliffs promote rockfall from above and ultimate cliff retreat resulting in smaller butte areas through time. Most of the rim slopes and canyons are steep-sided, mantled by rock debris, and contain relatively deep box canyons all of which are indicators of the rapid rates of erosion. There are many locations around the main platform that show naturally occurring small-scale solifluction, sliding, and slumping. The entire platform is tilted by several degrees to the north-northeast and is divided here into three geomorphic units: 1) a highly dissected, more rugged tableland to the north, bounded in the south by Devils Canyon; 2) an adjoining broad, central table bordered to the south by the deeply incised drainage of Schleichart Draw; and 3) a southern table which is dissected into a northern and southern unit by Davis Draw.

Geology

Regional bedrock consists of the Late Cretaceous Pierre Shale, Fox Hills sandstone, and the Hell Creek Formations. Overlying Tertiary rocks include the Ludlow and Tongue River Formations. Both the Pierre and Fox Hills units outcrop further south, outside of the study area.

The oldest rocks in the study area are the Hell Creek Formation clay, carbonaceous shale, siltstone, and sandstone units. The Formation is exposed in a small window along Bull Creek and major drainages at the base of the North Cave Hills. The Cretaceous-Tertiary contact is gradational and poorly exposed. Thus, is has been generally assigned to the lower-most coal unit in the overlying Tertiary rocks.

The lower-most Tertiary Ludlow Formation consist of gray to buff colored and relatively unconsolidated sandstone, siltstone, and clayey sand and silt units that weather yellowish gray. Occasional cross-bedding and ripple marks are evident in the sandy parts and ironstone concretions are ubiquitous throughout. Lignite coal and ligniferous shale units, referred to as 'blackjack', are ubiquitous in the Ludlow. The lower 200 feet of the Formation is designated as 'unnamed coal beds'. Above the lower zone, the major coal units are the Lonesome Pete coal zone, coal bed B, C coal zone, carbonate coal zone, and coal bed D.

The Ludlow-Tongue River Formation contact is sharp and marked by the appearance of the first massive sandstone outcrop. The lower-most sandstone, immediately above the Ludlow Formation, is yellow to brown, cross-bedded, slightly cemented with calcite, and massive having a thickness of 30-100 feet. The unit also forms the principle aquifer in the area. The upper sandstone unit is massive, non-calcareous, loosely consolidated and ranges up to 135 feet thick. A uranium ore zone consisting of impure lignite beds intercalated in siltstone and claystone units occurs about 110-150 above the base of the Formation. These coal units have high uranium concentrations and can be several feet thick. This unit also separates the lower and upper sandstone units.

Weathering and erosion of the above sequence has formed resistant sandstone rim rock capping the North Cave Hills. Tertiary Tongue River Formation rocks form the rim rock and are underlain by shallow slopes comprised of loosely consolidated sand, silt, and clay layers with intercalated coal seams of the Tertiary Ludlow Formation. Strata are relatively flat-lying with a regional dip of 1-2 degrees to the NE, but also display several areas of gentle folding and possibly faulting which control the orientation of local dip directions.

Curtiss (1955) noted “a well-defined right-angle joint pattern, which trends north-south, east-west is conspicuous in the basal Tongue River massive indurated sandstone, particularly in the North Cave Hills. Therefore, joint control may provide excellent permeability channel ways for the downward movement of uranium charged solutions into the Tongue River and Ludlow formations from the overlying White River sediments”*(before White River Formation was stripped away by erosion in the North Cave Hills)*. It is also possible that these same joints, which are evident at the base of many abandoned uranium mines, are conduits for entry of contaminants into underlying sandstone aquifers.

Surface Water Hydrology

The regional drainage pattern is strongly controlled by the regional structural grain, the prominent form being a conjugate set of fractures striking approximately N50-55°W and N10-50°E. Major, broad drainages dissecting the North Cave Hills have their headwaters close to the eastern edge of the tables and flow toward the northwest in the northern part and to the southwest in the southern part, essentially crossing the whole platform. Northern drainages are captured by Crooked Creek, which flows north around the North Cave Hills on their western side and then turns east to ultimately join the North Fork of the Grand River at Haley-Bowman Reservoir in North Dakota. Southern drainages are captured by Campbell Creek flowing toward the southeast along the southwestern side of the North Cave Hills. Campbell Creek flows into Bull Creek which joins the South Fork of the Grand River. The North and the South Forks of the Grand River are the major contributories to Shadehill Reservoir, the major reservoir in northwestern South Dakota. Drainages on the eastern edge of the North Cave Hills only cut back into the tables for relatively short distances of up to about one half of a mile. In the northern and central tables, these easterly drainages are all parts of the headwaters or contributories to Petes Creek which flows north along the eastern side of the Cave Hills and joins Crooked Creek at the northern end of the North Cave Hills. East-flowing drainages of the southern table are part of the headwaters of Big Nasty and Jack Creeks which both join the South Fork of the Grand River. Therefore, all water draining of the North Cave Hills ultimately enters the Shadehill Reservoir.

Channels leading out of the North Cave Hills are mostly filled with sediment and have broad channels with small to ill-defined thalwegs. This morphology suggests the system is not supply limited and that ample water is present to convey eroded sediment. On the prairie parts surrounding the buttes, channel morphology is more representative of a dry, supply limited system and is consistent with much of the western plains and Rocky Mountains that have been in a period of erosion and incision for approximately the past 140 years. Typical channels are narrow and deep and often contain between 1-3 terraces above the current channel. In addition, it is common that undercut banks fail promoting more stable conditions locally and in time will generate sufficient sediment in the channel to reestablish a stable channel system.

Several spring horizons, generally associated with thicker lignite seams, encircle the North Cave Hills on USFS administered land. Two prominent horizons occur just above and below the indurated sandstone cliffs of the Tongue River Formation, and a third just above the base of the grass-covered slopes. Many of these springs are perennial. In addition, several of the springs are developed for stock watering and at least two springs are known to be used for domestic supplies. All watersheds are marked by numerous small stock dams and several larger-sized reservoirs on and off USFS administered land. Smaller dams and reservoirs are generally designed for 100% capture without a spillway or stand-pipe design.

Historical Mining Activities

Only a few coal claims were located in Harding County prior to 1920. Uranium exploration began in 1954 when the Atomic Energy Commission decided to fly airborne surveys over the Slim Buttes (approximately 20 miles to the east of the Cave Hills). According to Curtiss (1955), "Messrs. Ellis and Fiegen, pilots from Spearfish, were scheduled to fly over the buttes, but a high wind precluded their operations. Instead, they flew over the Cave Hills and recorded high anomalies. As a result, they staked the first claims on August 15, 1954. Since that time, activity in this area has been intense."

Active mining started around 1954. Mine sites are located primarily within an approximately two-mile broad, northwest trending strip crossing the central North Cave Hills ("hot zone"). Mining was permitted under the General Mining Laws and Public Law 357, which required no form of restoration. Most mining and mining prospects are located on USFS administers land, but at least two actively mined sites and several prospects and exploration cuts and digs are situated on private land surrounding the North Cave Hills. These uranium mines are abandoned coal strip mines located on relatively flat areas along the top of the buttes. Mining consisted of the removal of up to 80 feet of overburden to reach the uranium bearing lignite beds ("ore zone").

Extensive mining activity occurred in the early 1960s in an effort to supply contracts for uranium, but all active mining in the area ceased shortly thereafter in 1964. Documented mine sites, spoils, exploration activities and subsequent erosion of spoils cover almost 1,000 acres. Most of the spoils were pushed over the edges of buttes onto the steep slopes below the rim rocks during mining (Figure 2). Additional spoils have been deposited down-slope by subsequent water and/or wind transport. At these sites, the sandstone cliffs are mostly covered, and the overall slope angles are highly over-steepened. The spoils are also mostly void of vegetation, and their composition is also conducive to water channeling and tunneling. All these conditions contribute to high erosion rates and also make these sites highly prone to sliding and slumping. At two sites, Bluffs B and H, the spoils have slid and/or slumped onto adjacent private land, and subsequent sheet erosion of these deposits formed shallow depositional cones and veneers of sediment down gradient (Figure 3). Uncontrolled, channeled runoff from the spoils locally also caused up to approximately 12 feet deep gully erosion. At several sites highly radioactive material was left exposed on the pit floors or spoils.

In addition to the mining sites, numerous prospecting pits or contour benches are visible in the field on both USFS administered and private lands and have been mapped and documented in the area (Pioneer, 2005). These mostly obvious, but sometimes also overgrown and sublime features were made by dozers or backhoes to expose outcroppings of fresh rock. One mine site on private land on Flint Butte, located immediately northeast of Ludlow, has been hypothesized as a potential source of molybdenosis in cattle grazing at and in the near vicinity of this site (Stone et al., 1983).

<u>Control Structures and Previous Mitigation Activities</u>

In 1987, the USFS installed five sedimentation ponds (constructed using a common standpipe design) on USFS administered land to contain/control runoff and offsite migration of sediments from the Riley Pass Mine, the site with the largest erosion potential. Ponds #1 and #2 were installed on the eastern side of the pass just above the relocated Riley Pass Road in the headwaters of Petes Creek. Ponds #3, #4, and #5 were constructed on the western side in Schleichart Draw just below the mine site,. Another pond is planned to be constructed for capturing runoff into Petes Creek from the spoil piles along the northeastern side of Bluff B. This part of the drainage is presently not contained by any control structure.

A series of other ponds and reservoirs exists further down the Schleichart draw along the western side of the North Cave Hills. According to a chronologic series of aerial photographs, Schleichart Dam Reservoir was constructed in1935 by the Civil Conservation Corps (CCC) (Laurie Walters-Clark, USFS, personal communication) before regional uranium mining operations began. Further downstream within this drainage, the Schleichart Ducks Unlimited Pond was completed in late summer of 1987 as part of a (now abandoned) wildlife habitat improvement project. Just at the USFS boundary of this drainage on land recently acquired by the USFS is Brown Reservoir. This reservoir captures all of Campbell Creek and Davis Draw drainages. Brown Reservoir was most likely constructed before 1958, but after 1938 (probably in the early 1950’s; J.D. Brown, local rancher, personal communication).

Figure 2: Historical photograph of overburden disposal at Bluff H (from USDA-USFS impact report, 1964).

Figure 3: Current Bluff B overburden.

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The sedimentation ponds filled up rapidly over the years. Ponds #3, 4, and 5 were cleaned out by the USFS in 1990, and all ponds (#1-5) were cleaned out again in 1997 and 2004. The competence of these ponds was tested during several strong rainfall events. Many stock dams and reservoirs on private land overflowed and were breached during a significant rain event that occurred in 1992 when a highly localized thunderstorm dumped up to 10 inches of rain within approximately three hours along the northeastern side (Randy Feist, local rancher; personal communication) and up to 2-4 inches along the western side of the North Cave Hills (Mert Clarkson, local rancher; personal communication). This event caused localized flooding and breaches/overflow of stock dams and sedimentation ponds on USFS administered land. In a possible response to this event, the culvert at pond #2 had to be replaced and the road reconstructed in 1993. During another event in 1995, the culvert in pond #5 failed and was repaired and the road was reconstructed in 1997. Sedimentation ponds were subsequently cleaned out and repaired after this event (Laurie Walters-Clark, USFS, personal communication). The sediments removed from these ponds were dumped at a designated site within Bluff B. At this time it is not known how these or other significant rainfall events during- and post-mining affected the spread of mine spoils and associated metals and radionuclide loads within the local and regional drainages.

Previous Investigations

Previous investigations were mainly focused on USFS administered land and consisted of surface soil, sediment, and water samples. A comprehensive compendium of all data and conclusions is presented in the USFS-Pioneer Investigations Report (2005). These studies document higher than normal, though widely varying, concentrations of target analytes in background samples of soil, sediment, and water (as compared to general US soil, water, and lignite data). They also show a wide variance in concentrations of target analytes in mine spoils and in sediments and surface water of drainages impacted by mining. Significant changes in contaminant concentrations are obvious for surface water samples taken at the same site, but in different years (1999 and 2000) during the month of August (Pioneer, 2005; Appendix C).

Concentrations range from below the established average background to 10 times higher for sediment samples in impacted drainages and several 100 times higher for spoil samples at mapped mine sites. Bluffs B and H were identified as the areas of most concern. Bluff B is of concern due to the large amount of disturbance resulting from past mining activity while Bluff H appears to have a higher contaminant level. Petes Creek and Schleichart Draw were shown to be the two drainages most impacted by the mining activities.

Project Objectives

The overall objective for this investigation was to determine whether heavy metal and radionuclide environmental contaminants have been transported from historical mine sites on lands administered by the Forest Service onto private lands. Mechanisms of environmental transport where though to include:

1. Erosion of spoil sediments through adjacent drainages;
2. Dissolution of hazardous metals within runoff water; and
3. Erosion/deposition of small diameter spoils particles by wind transport.

The field sampling objectives were developed to ascertain whether surrounding private lands have been negatively impacted by migrating contaminants and whether such contaminants pose a potential health risk to the surrounding population. As a result, the field sampling protocol were developed to:

1. Establish background concentrations and variability for the environmental contaminants (target analytes) addressed within this study;
2. Determine whether present contaminant concentrations exist in surface waters and sediments coming off USFS administered land and whether they can be attributed to impacts stemming from historical uranium mining and exploration;
3. Discriminate whether sources of environmental contaminants found within down-drainage surface waters and sediments on private lands can be attributed to historical mining and exploration operations on USFS administered land, from naturally occurring mineralization, or from other historical mining and exploration activities in the drainage;
4. Determine if heavy metals and radionuclides exist in aquifers used by private parties for domestic and/or stock use in a perimeter of 5 miles around the North Cave Hills area, and establish potential sources and migration pathways if present;
5. Quantify whether wind erosion serves as a potential contaminant migration source from mine spoils on USFS administered land;
6. Determine if down-gradient contamination within ambient air dust may be attributed to mine spoils on USFS administered land.

For the purposes of this preliminary report, only results and discussions related to objectives 2 and 3 above will be addressed as related to surface water. Other project objectives will be addressed within the final report.

Field Sampling Strategies

As outlined above, previous site investigations primarily focused on environmental conditions within USFS administered land, and had not addressed potential environmental impacts that may have migrated offsite onto private lands. The sampling strategy developed to discern potentially impacted surface waters was a “watershed” approach. It was assumed that all runoff water and eroded sediments (except for wind erosion) would ultimately end up in the adjacent drainages and subsequently migrate downstream through the drainage networks. Based upon the overall goal of assessing the environmental impacts of historical mining activities on surrounding private lands, the surface water sampling events were divided into two separate phases, Phase I and Phase II. For the initial Phase I sampling events that occurred during June 2006, target analyte concentrations of all potentially impacted drainages leaving USFS administered land were determined at or near the USFS-administered/private land boundary. Additionally, background concentrations for the target analytes were established for drainages based on sampling locations of drainages assumed to not be impacted by the mining activities (see Background Sampling section below). The gathered data were subsequently used to evaluate which drainages were most heavily impacted. Total and dissolved metals concentrations were analyzed for most water samples collected (some Phase I, all Phase II samples) to ascertain the primary phase of potential contaminants mobility (e.g., associated with > 0.45 µm sized sediments or sub-colloidal) within the watershed.

After initial evaluation of the Phase I results, the drainage with the highest environmental concern was selected for Phase II sampling. For this phase,, downstream sampling continued to a point where target analyte concentrations were comparable to established background levels.. Phase I results indicated that the Petes Creek drainage appears to be the most heavily impacted, and thus was selected for Phase II sampling.

Target Analytes

Target analytes for metals and radionuclides chosen for this study (Table 1) were similar to those used within previous investigations, thus allowing direct comparability of the data (except for Denver, Knight, and Piesold, 1990 and 1991). Analytical methods and procedures for determination of analyte concentration were also similar to those employed within previous studies with the exception of our study analyzing for both total and dissolved metals concentrations for the surface water samples. In addition, this study analyzed for select anions and other water quality characteristics (Table 2) to further characterize contaminant geochemical mobility.

Background Sampling

Previous investigations determined background concentrations for the target analytes in soils in undisturbed areas within the same stratigraphic interval as the mined lignite (“ore zone”) and in sediments and surface water in drainages deemed to be not impacted by mining activities. Judging by these data (a compilation of all data and average concentrations are listed in Portage, 2005, Appendices A and B), soil contaminant concentrations vary widely depending on two factors:

1. Sample location within or outside of the “hot zone” crossing the central North Cave Hills; and
2. Soil type, meaning a lignite or non-lignite based sample.

Based on map analysis and an initial field reconnaissance performed in March 2006, three control drainages were selected to represent various “background” conditions. Sampling locations for these drainages are all near or at the USFS/private land boundary, and surface water samples were taken at these sites for establishing background.

Table 1. Summary of target metal and radionuclide analytes and analytical methods employed.

Analyte Name	Chemical Symbol	Soil/ Sediment	Air Filter	Surface Water	Ground Water
Arsenic	As	SW6020[1]	SW6020[1]	E200.8[2]	E200.8[2]
Copper	Cu	SW6020[1]	SW6020[1]	E200.8[2]	E200.8[2]
Molybdenum	Mo	SW6020[1]	SW6020[1]	E200.8[2]	E200.8[2]
Selenium	Se	SW6020[1]	SW6020[1]	E200.8[2]	E200.8[2]
Lead	Pb	SW6020[1]	SW6020[1]	E200.8[2]	E200.8[2]
Thorium	Th	SW6020[1]	SW6020[1]	E200.8[2]	E200.8[2]
Radium	Ra	SW6020[1]	SW6020[1]	E200.8[2]	E200.8[2]
Uranium	U	SW6020[1]	SW6020[1]	E200.8[2]	E200.8[2]
Vanadium	V	SW6020[1]	SW6020[1]	E200.8[2]	E200.8[2]
Radium-226	Ra-226	E903.0[3]	E903.0[3]	E903.0[3]	E903.0[3]
Uranium-235	U-235	E907.0[4]	E907.0[4]	E907.0[4]	E907.0[4]

[1] Standard EPA method for ICP/MS analysis of Total Recoverable Metals in solids;
[2] Standard EPA Method for ICP/MS analysis of Total Recoverable Metals in water;
[3] Standard EPA Method for Analysis Radionuclides in Water Using Radiochemical Methods (also adapted to solids);
[4] Standard EPA Method measuring Total Radioactive Uranium in water (also adapted to solids).

1. NCH SW 21: Smaller northwesterly drainage with an area of approximately 2/3 of one square mile fed by Cox Springs #'s 1 and 2. No mining or exploration activities are documented in this watershed. This drainage represents "pristine" conditions outside of the "hot zone" in the highly dissected northern part and flows into Crooked Creek;
2. NCH SW 25: Uppermost drainage of Campbell Creek draining almost exclusively private land with an area of approximately one square mile. This sample location is situated at the upper end of a stock dam. Any drainages coming off USFS administered land on the southwestern side enter Campbell creek below this point; and
3. NCH SW 26: Icebox Canyon and the drainage immediately to the west fed by Travers Spring #2 which drain part of the "hot zone" on the southwestern side. No mining or exploration activities are documented in this watershed. This site is a relatively large side drainage (approximately one square mile) of Schleichart Draw and Campbell Creek. The sampling location is located at the upper end of a stock dam on State land.

Table 2. Summary of water quality and radiochemical analytical methods employed.

Analysis	Standard EPA Surface Water Method
Alkalinity (CO_3^{2-}, HCO_3^-, H_2CO_3)	A2320 B
Solids, Suspended Volatile	A2540
Solids, Total Suspended	E160.2
Anions by Ion Chromatography (NO_3/NO_2, SO_4^{2-})	E300.0
Phosphorus, Total	E365.1
Gross Alpha	E900.0
Radium 226, Total	E903.0
Radium 228, Total	E904.0
Thorium 230, Total	E907.0
Thorium, Isotopic	E907.0
Uranium, Isotopic	E907.0

<u>Surface Water Quality Standards</u>

The Draft Applicable or Relevant and Appropriate Requirements for the Riley Pass-Mine Site, South Dakota Department of Environment and Natural Resources (DENR) Water Quality Standards (DENR 2002 as presented in Pioneer 2002) are shown in Table 3. These results were used to compare regional surface water results to DENR water quality standards.

Surface Water Results

Results of SDSM&T's preliminary surface water investigations of the North Cave Hills region are presented within this section. This section will present key preliminary findings from surface water sampling that occurred during June and July 2006. Discussions regarding surface water quality parameters (Table 2) and their effect on contaminant fate and transport will be not presented, primarily because these analytical findings have yet to be interpreted. A comprehensive report, scheduled to be completed by December 31, 2006, will present and discuss all findings pertaining to surface water, groundwater, soil/sediment, and air sampling events that occurred within the North Cave Hills region.

As discussed within the Field Sampling Strategies section above, sampling events for the determination of surface water quality of the North Cave Hills region was divided into two separate sampling events. Phase I consisted of collecting available surface water samples within drainages located at the interface between USFS administered land and private land. Phase II included a comprehensive sampling program down the Petes Creek drainage located east of the historical minesites. Previous investigations (Pioneer 2002) had demonstrated that elevated heavy metal and radionuclide concentrations existed in sedimentation ponds #1 and 2 which are located within the Petes Creek headwaters.

Table 3. South Dakota DENR surface water quality standards (SD DENR 2002).

Analyte Name	Human Health [μg L^{-1}]	Aquatic Life Value Concentrations: Acute @ 100 mg L^{-1} hardness [μg L^{-1}]	Aquatic Life Value Concentrations: Chronic @ 100 mg L^{-1} hardness [μg L^{-1}]
Arsenic	0.018	360	190
Cadmium		3.7	1.0
Chromium III		550	180
Chromium VI		15	10
Copper	1,300	17	11
Lead		65	2.5
Mercury	0.14	2.1	0.012
Molybdenum			
Nickel	610	1,400	160
Radium-226, 228			
Selenium		20	5
Silver		3.4	
Thorium			
Uranium		20	
Vanadium			
Zinc		110	100

Background Results

Results for the three background surface water sampling sites (NCH SW 21, 25, and 26) are presented Figure 4 and Table A1 (in Appendix). Notable concentrations of total metals found within the background samples included 0.017 to 0.031 mg L^{-1} (average 0.024 mg L^{-1}) for arsenic and 0.012 to 0.021 mg L^{-1} (average 0.017 mg L^{-1}) for uranium, suggesting that, on a regional basis, naturally elevated concentrations of metals and radionuclides exist and are likely not attributable to historical mining activities. For the environmental assessment of other Phase I and II sites, the average concentrations for total metals and radionuclides measured found at the three background sites were used. The background concentrations for contaminant metals established for surface water in this study are similar to previous studies (Pioneer 2005).

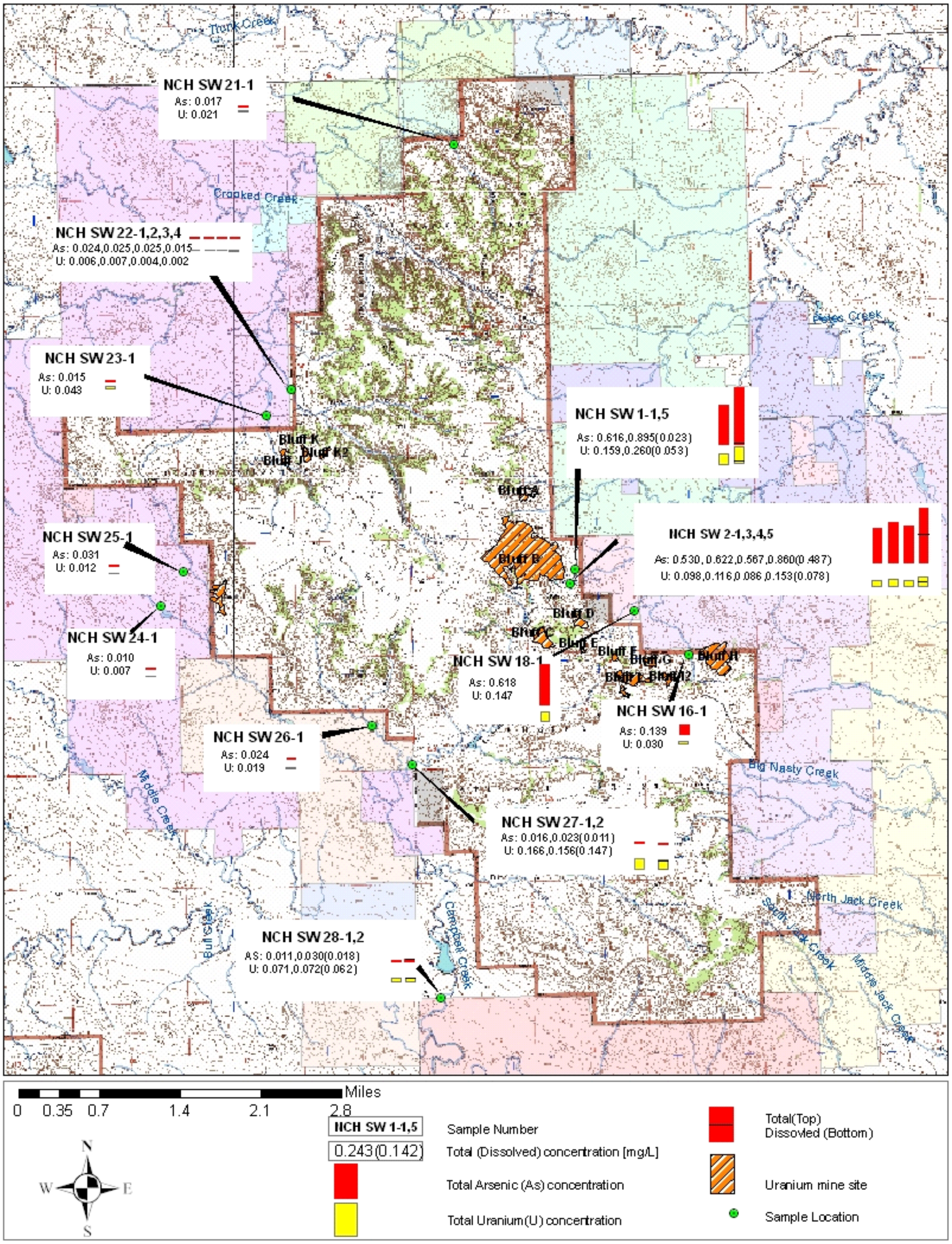

Figure 4: North Cave Hills Phase I surface water sampling locations and analytical results for arsenic and uranium.

Phase I Results

After reviewing available hydrologic maps and through initial field reconnaissance, approximately 26 potentially impacted surface water sampling sites located at the USFS-administered/private land boundary were determined. However during our Phase I field sampling site investigations performed in June 2006, not all of the identified drainages were flowing or had standing surface water available for sampling, and thus Phase I surface water samples were collected only at sites where appreciable stream flow or standing water existed. Phase I samples were analyzed for water quality parameters outlined within Tables 1 and 2. In addition, select samples were analyzed for radiochemical parameters (gross alpha, uranium 225, radium 226) at locations that exhibited significantly elevated total uranium concentration from our preliminary total uranium analytical results. Discussion pertaining to radiochemistry results will not be discussed within this report.

The majority of the Phase I metal and radionuclide results are reported as total metal concentrations. Dissolved and total metal concentrations are reported only for samples NCH SW 1-5, 2-5, 27-2, and 28-2. For Phase II, it was decided that both total and dissolved metals would be reported to better characterize metal phase loadings within the individual water columns. A summary of the total and dissolved (if measured) metals and radionuclide concentrations from the Phase I study are presented in Table A2 (in Appendix). Graphical site concentrations for two contaminants thought to be of greatest concern, uranium and arsenic, are presented in Figure 4.

The area with the highest concentrations for the two contaminants of highest concern, arsenic and uranium, were found in the area adjacent to and east of the minesites (NCH SW 1, 2, 16, 18) in the headwaters of the Petes Creek drainage. Samples taken at the discharges of sedimentation ponds #2 (NCH SW 1) and #1 (NCH SW 2) both contained the highest average concentrations of total arsenic (0.751 and 0.643 mg L^{-1} averages respectively) and total uranium (0.209 and 0.113 mg L^{-1} averages respectively) of the Phase I sampling locations. These sedimentation ponds are both located down gradient of Bluff B collecting surface and sediment runoff from the spoil piles on the eastern side of the Riley Pass mine (Figure 3). When compared to established background concentrations, sites NCH SW 1, 2, and 18 exceeded existing background concentrations for all eight total metal concentrations, with arsenic (22 to 38x background), vanadium (9 to 21x), lead (11 to 35x), thorium (11 to 24x), and uranium (5 to 15x) occurring at the highest levels relative to background. For site NCH SW 16, only total arsenic (6x background) exceeds 3x background.

For the remaining sites sampled during Phase I, only sites NCH SW 27 and 28 had concentrations exceeding 3x background. Site NCH SW 27 is located near the terminus of Schleichart Draw as it crosses the USFS road onto private land (Figure 5). This site exceeded 3x background concentration for total uranium (0.161 mg L^{-1} average, or 9 to 10x background) and molybdenum (0.058 mg L^{-1} average, or 2 to 4x background). Further down Campbell Creek below an existing stock dam (Figure 6), site NCH SW 28 had total uranium (0.071 mg L^{-1} average, or 4x background) and molybdenum (0.062 mg L^{-1}, or 3 to 4x background) concentrations only slightly exceeding 3x established background. All other Phase I sampling sites were less than 3x background for the 8 metals and radionuclides analyzed.

Figure 5: NCH SW 27 sampling location located near the terminus of Schleichart Draw as it crosses the USFS road onto private land.

Figure 6: NCH SW 28 sampling location below an existing stock dam within the Campbell Creek watershed.

Phase II Results

Comprehensive sampling to determine the extent of metal and radionuclide contamination along Petes Creek and associated watersheds was performed during Phase II on June 21 and 22, 2006. Phase II results have been sub-divided into two sampling areas:

1. Upper Petes Creek drainage located between the interface of USFS administered land/private property closest to the abandoned mines and flowing northeast to Tufte Road (Figure 7 and Table A3 in Appendix).
2. Lower Petes Creek drainage located north of Tufte Road and continuing north to the confluence of Crooked Creek. This study area continues down Crooked Creek eastward until it passes beneath South Dakota State Route 85 (Figure 8 and Table A4 in Appendix).

The drainage below site NCH SW 16 was sampled to determine the extent of contamination potentially associated with Bluff H spoils (Figure 9). Sample NCH SW 29 was taken immediately downgradient of a lignite spring discharge (Figure 10). Results from this lignite spring were all less than 3x background for the 8 metals analyzed, thus suggesting that regional lignite outcrop seeps and springs may not be a significant source of localized heavy metals and radionuclides within the upper Petes Creek drainage. Other lignite outcropping sampled within the upper Petes Creek drainage (NCH SW 55, 56) also had less than 3x background for the eight metals analyzed, further suggesting elevated concentrations found within Petes Creek may not be attributed to localized exposed lignite outcroppings.

Further downgradient of NCH SW 29, sites 44 (west fork side drainage; sampled cow hove imprints), NCH SW 45 (lower confluence of drainages; standing water), and NCH SW 46 (upper east drainage; sampled cow hove imprints) all exhibited concentrations greater than 3x background for all metals analyzed. Of note, uranium was found to be significantly greater than background (0.085 to 0.393 mg L^{-1}, or 5 to 23x background) for these 3 sites.

The area that had the most significant concentrations of the eight metals and radionuclides was located within the upper Petes Creek basin nearest an unnamed tributary flowing from Bluff B spoils. This tributary flows cross Riley Pass Road/USFS Route 3120 east of sedimentation ponds #1 and 2, and historical sediment flows within this tributary have been documented within the Portage (2005) study. Waste materials (spoils and overburden) have been documented by this study as a major source of sedimentation into Petes Creek. Significant sedimentation has occurred within the lower reaches of this tributary, especially as surface water flow velocities decrease due to a lower gradient near and beyond the confluence with the middle fork of Petes Creek (Figures 11, 12) Currently there is no sedimentation pond to collect surface runoff flowing from Bluff B spoils and overburden within this unnamed tributary. NCH SW 43, collected within the unnamed tributary prior to discharge into Petes Creek, had metal concentrations all exceeding 3x background. Of note, the highest concentrations of all

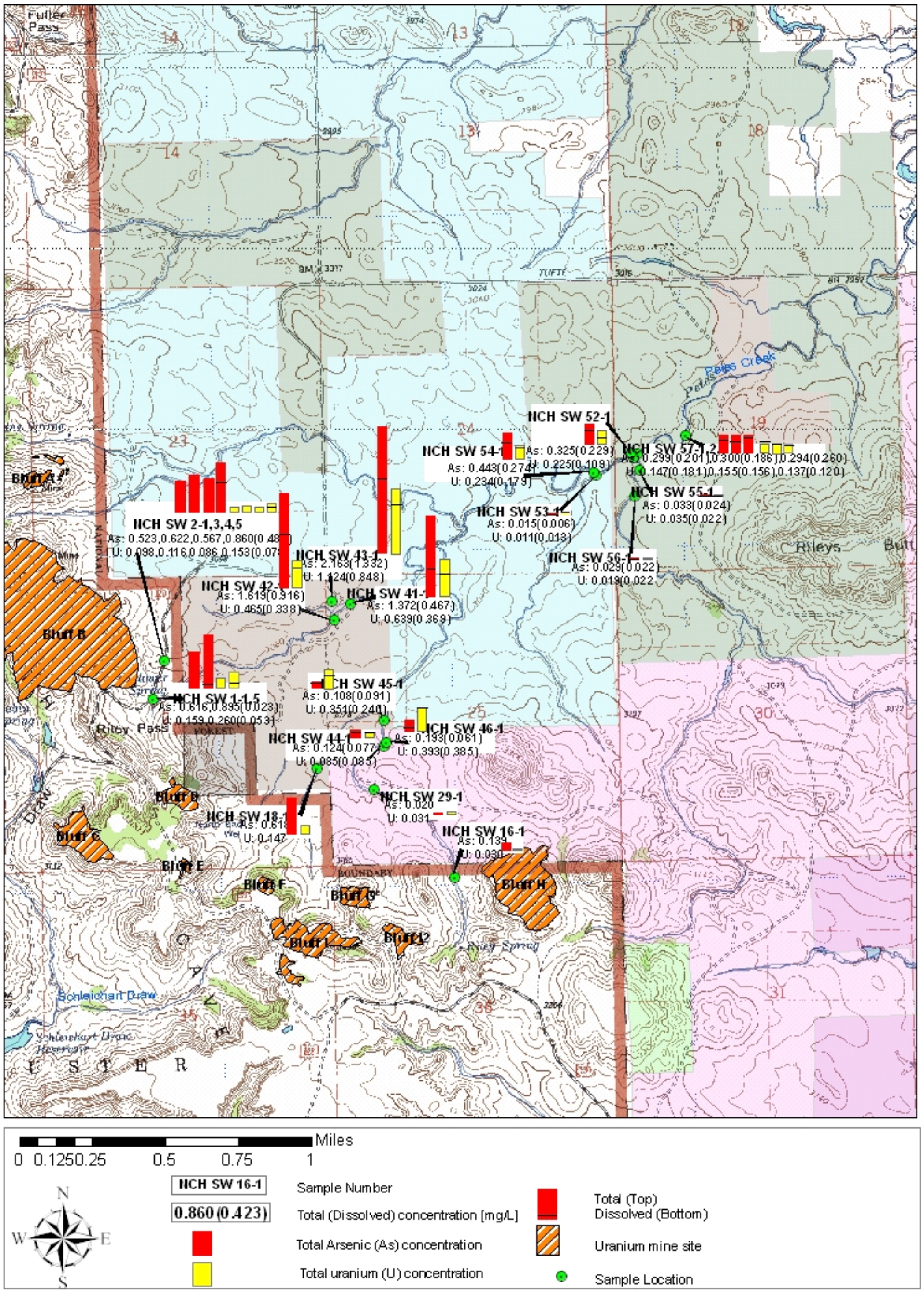

Figure 7: Upper Petes Creek Phase II surface water sampling locations and analytical results for arsenic and uranium.

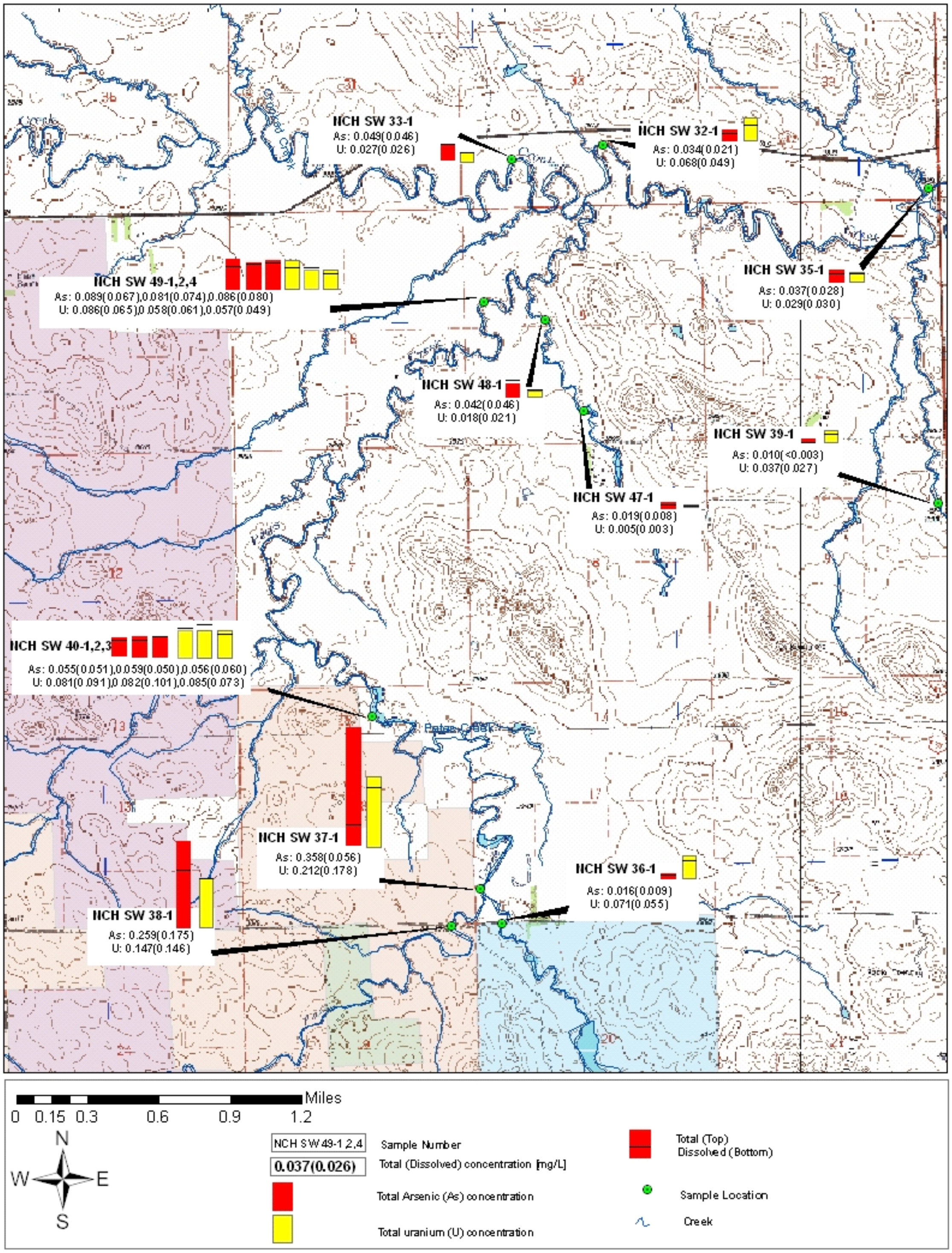

Figure 8: Lower Petes Creek Phase II surface water sampling locations and analytical results for arsenic and uranium

Figure 9: Bluff H spoils located up-gradient of site NCH SW 16

Figure 10: NCH SW 29 sampling location immediately downgradient of a lignite spring discharge.

Figure 11: Area of significant sedimentation within the lower reaches of an unnamed tributary of Petes Creek near NCH SW 43 sampling location.

Figure 12: Close-up showing extent of sedimentation within unnamed tributary of Petes Creek near NCH SW 43.

metals including total arsenic (2.163 mg L^{-1}, or 91x background), lead (0.860 mg L^{-1}, or 86x background), thorium (0.106 mg L^{-1}, or 26x background), uranium (1.124 mg L^{-1}, or 65x background), and vanadium (0.477 mg L^{-1}, or 33x background) were found at the highest concentrations observed within the upper Petes Creek drainage. NCH SW 42, located within Petes Creek down gradient of sedimentation ponds #1 and 2, and NCH SW 43, located within Petes Creek down gradient of the unnamed tributary, both had metals concentrations all significantly greater than 3x background.

Further down Petes Creek, sites NCH SW 52, 54, and 57 show that the metals naturally attenuate. For example, total uranium within Petes Creek decreases from 0.639 mg L^{-1} (37x background) at site NCH SW 41 to 0.146 mg L^{-1} average (9x background) for site NCH SW 57 within this reach. In addition, the ratio of dissolved metals to total metals for most analytes increases significantly within this same reach of Petes Creek, suggesting that the major source of metals is already in the dissolved phase, and not associated with fine, non-colloidal (> 0.45 µm) particles. Two lower side-tributaries (sites NCH SW 53, 56) draining the area to the east of Bluff H both display less than 3x background for all analytes, and thus are not a significant source of contaminant loading into Petes Creek.

The lower Petes Creek drainage sampling site locations and results are shown in Figure 8 and Table A4 (in Appendix). An unnamed side tributary flows into Petes Creek immediately north of Tufte Road. This tributary drains the upper Flint Buttes watershed (south of Tufte Road) in addition to a portion of the watershed containing an abandoned (Flint Butte) uranium minesite located due north and east of the town of Ludlow (across SD SR85). This minesite is significant in size (similar to Bluff B) and is located on private property. Contaminant loadings from these drainages flowing into Petes Creek (NCH SW 36) were all below 3x background concentrations except for total uranium (0.071 mg L^{-1}, or 4x background).

Attenuation of contaminant loading within Petes Creek continues downstream. At the last sampling location prior to discharge into Crooked Creek (NCH SW 49), only arsenic (0.085 mg L^{-1} average, or 4x background), copper (0.108 mg L^{-1} average, or 4x background), molybdenium (0.077 mg L^{-1} average, or 4x background), and uranium (0.067 mg L^{-1}, or 4x background) exceeded 3x established background. The unnamed side tributary (NCH SW 47, 48) upstream of the Crooked Creek confluence with Petes Creek displays analyte concentrations all less than 3x background, and thus is not a significant source of contaminant loading into Petes Creek.

Crooked Creek prior to the confluence with Petes Creek (NCH SW 33) has analyte concentrations less than 3x background. Downstream of this confluence with Petes Creek (NCH SW 32), only total copper (0.104 mg L^{-1}, or 4x background), molybdenum (0.065 mg L^{-1}, or 4x background), and uranium (0.068 mg L^{-1}, or 4x background) concentrations were greater than 3x background. At the final sampling location where Crooked Creek flows beneath SD RT 85 (NCH SW 35), all analyte concentrations were below 3x background, with total arsenic at 0.037 mg L^{-1} (1.5x background) and uranium at 0.029 mg L^{-1} (1.7x background). A side tributary draining an area east of SD SR85 and north of the Flint Butte abandoned uranium minesite on private property (northeast of Ludlow; site NCH SW 39) had only elevated concentration of copper (0.222 mg L^{-1}, or 8x background); all other analytes were less than 3x background.

Conclusions and Recommendations

This report addresses surface water results from the "watershed" study used to assess off-site migration of mining spoils and associated metals and radionuclides from the North Cave Hills region of USFS administered lands. Results from this study indicate that widespread heavy metal and radionuclide contamination exists within the Petes Creek drainage located on private lands east of the North Cave Hills complex. The source of contamination appears to be from both controlled and uncontrolled sediment flows from the Riley Pass (Bluff B) minesite. Natural attenuation of contaminant loadings is occurring within the Petes Creek, and Crooked Creek drainage. Contaminant concentrations were less than 3x background for all analytes measured at SD SR85, located at the lend of the drainage study area.

Other key findings observed during this surface water study include:

1. Arsenic and uranium mobility and attenuation within the Petes Creek watershed vary considerably. Arsenic attenuation readily occurs within the upper reaches of Petes Creek, and is likely attributable to the highly oxidative conditions present, possibly promoting the formation of insoluble (and likely less mobile) arsenate [As(V)] species instead of soluble and highly mobile arsenite [As(III)] species. Conversely, oxidative conditions typically result in the preferential formation of mobile uranyl [U(VI)] species versus immobile uraninite [U(IV)] species. Studies are currently underway to further understand the relationship between these (bio)geochemical conditions and its relationship to contaminant mobilization/immobilization.
2. Sedimentation Ponds #1 and 2 are currently not effective in capturing surface water and sediment loading from Bluff B spoils. The relatively low dissolve metal concentrations (such as arsenic and uranium) compared to their corresponding total metal concentrations for samples collected immediately downstream of the pond discharges suggests a significant mass of sediment (>0.45 µm) is effectively passing through these engineered structures.
3. The largest source of contaminant loading within the Petes Creek drainage is from the unnamed, uncontrolled (i.e., no current sedimentation pond in place) tributary originating in the vicinity of Bluff B spoils. This drainage is located north of the sedimentation pond #1 and 2 drainages.
4. The various exposed lignite outcroppings within the upper and lower Petes Creek drainage do not appear to be a significant source of contaminant loadings within the Petes Creek watershed. Detailed geochemical and microscopic studies are currently underway to confirm these findings.
5. The watershed draining the Flint Butte abandoned minesite near Ludlow (abandoned uranium minesite on private property) contributes to the overall contaminant loading within the Petes Creek watershed. A future detailed

analysis of the Flint Butte watershed is recommended to quantify these potential contaminant loadings.

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Appendix

Table A1: North Cave Hills background surface water analytical results

Sample ID	Date collected	V (mg/L)		Cu (mg/L)		As (mg/L)		Se (mg/L)		Mo (mg/L)		Pb (mg/L)		Th (mg/L)		U (mg/L)	
		Total	Diss	Total	Diss	Total	Diss	Total	Diss	Total	Diss	Total	Diss	Total	Diss	Total	Diss
NCH-SW-21-1	6/3/2006	0.007		0.028		0.017		<0.003		0.028		0.006		0.003		0.021	
NCH-SW-25-1	6/3/2006	0.033		0.029		0.031		<0.003		0.004		0.019		0.006		0.012	
NCH-SW-26-1	6/3/2006	0.004		0.031		0.024		0.003		0.022		0.006		0.003		0.019	

Table A2: North Cave Hills Phase I surface water analytical results

Sample ID	Date collected	V (mg/L)		Cu (mg/L)		As (mg/L)		Se (mg/L)		Mo (mg/L)		Pb (mg/L)		Th (mg/L)		U (mg/L)	
		Total	Diss	Total	Diss	Total	Diss	Total	Diss	Total	Diss	Total	Diss	Total	Diss	Total	Diss
NCH-SW-1-1	6/3/2006	0.278		0.162		0.616		0.042		0.248		0.214		0.072		0.159	
NCH-SW-1-5	6/20/2006	0.298	0.029	0.211	0.039	0.895	0.023	0.056	0.041	0.220	0.856	0.349	0.011	0.097	0.005	0.260	0.053
NCH-SW-2-1	6/3/2006	0.124		0.087		0.523		0.012		0.134		0.116		0.051		0.098	
NCH-SW-2-3	6/4/2006	0.176		0.114		0.622		0.013		0.121		0.151		0.045		0.116	
NCH-SW-2-4	6/4/2006	0.300		0.090		0.567		0.008		0.236		0.130		0.060		0.086	
NCH-SW-2-5	6/20/2006	0.203	0.080	0.138	0.045	0.860	0.487	0.024	0.010	0.137	0.120	0.198	0.041	0.059	0.005	0.153	0.078
NCH-SW-16-1	6/3/2006	0.006		0.032		0.139		<0.003		0.108		0.005		<0.003		0.030	
NCH-SW-18-1	6/3/2006	0.294		0.162		0.618		0.042		0.209		0.255		0.073		0.147	
NCH-SW-21-1	6/3/2006	0.007		0.028		0.017		<0.003		0.028		0.006		0.003		0.021	
NCH-SW-22-1	6/3/2006	0.003		0.033		0.024		<0.003		0.006		0.009		<0.003		0.006	
NCH-SW-22-2	6/3/2006	<0.003		0.034		0.025		<0.003		0.009		0.004		<0.003		0.007	
NCH-SW-22-3	6/4/2006	<0.003		0.033		0.025		<0.003		0.003		0.005		<0.003		0.004	
NCH-SW-22-4	6/4/2006	ND		ND		0.015		ND		ND		ND		ND		0.002	
NCH-SW-23-1	6/3/2006	0.005		0.069		0.015		<0.003		0.045		0.006		0.003		0.043	
NCH-SW-23-2	6/20/2006	0.013	0.007	0.051	0.038	0.027	0.017	0.007	<0.003	0.030	0.026	0.010	0.004	0.005	0.003	0.026	0.019
NCH-SW-24-1	6/3/2006	0.006		0.014		0.010		<0.003		0.007		0.009		0.003		0.007	
NCH-SW-25-1	6/3/2006	0.033		0.029		0.031		<0.003		0.004		0.019		0.006		0.012	
NCH-SW-26-1	6/3/2006	0.004		0.031		0.024		0.003		0.022		0.006		0.003		0.019	
NCH-SW-27-1	6/3/2006	0.008		0.079		0.016		<0.003		0.045		0.011		0.003		0.166	
NCH-SW-27-2	6/20/2006	0.013	0.007	0.081	0.069	0.023	0.011	0.009	<0.003	0.071	0.057	0.006	<0.003	0.005	0.003	0.156	0.147
NCH-SW-28-1	6/3/2006	0.004		0.072		0.011		<0.003		0.053		0.006		0.003		0.071	
NCH-SW-28-2	6/20/2006	0.012	0.008	0.087	0.076	0.030	0.018	0.007	<0.003	0.072	0.061	0.005	<0.003	0.004	0.003	0.072	0.062

Table A3: Upper Petes Creek Phase II surface water analytical results

Sample ID	Date collected	V (mg/L)		Cu (mg/L)		As (mg/L)		Se (mg/L)		Mo (mg/L)		Pb (mg/L)		Th (mg/L)		U (mg/L)	
		Total	Diss	Total	Diss	Total	Diss	Total	Diss	Total	Diss	Total	Diss	Total	Diss	Total	Diss
NCH-SW-1-1	6/3/2006	0.278		0.162		0.616		0.042		0.248		0.214		0.072		0.159	
NCH-SW-1-5	6/20/2006	0.298	0.029	0.211	0.039	0.895	0.023	0.056	0.041	0.220	0.856	0.349	0.011	0.097	0.005	0.260	0.053
NCH-SW-2-1	6/3/2006	0.124		0.087		0.523		0.012		0.134		0.116		0.051		0.098	
NCH-SW-2-3	6/4/2006	0.176		0.114		0.622		0.013		0.121		0.151		0.045		0.116	
NCH-SW-2-4	6/4/2006	0.300		0.090		0.567		0.008		0.236		0.130		0.060		0.086	
NCH-SW-2-5	6/20/2006	0.203	0.080	0.138	0.045	0.860	0.487	0.024	0.010	0.137	0.120	0.198	0.041	0.059	0.005	0.153	0.078
NCH-SW-16-1	6/3/2006	0.006		0.032		0.139		<0.003		0.108		0.005		<0.003		0.030	
NCH-SW-18-1	6/3/2006	0.294		0.162		0.618		0.042		0.209		0.255		0.073		0.147	
NCH-SW-29-1	6/3/2006	0.011		0.044		0.020		<0.003		0.040		0.012		0.005		0.031	
NCH-SW-41-1	6/21/2006	0.260	0.036	0.202	0.070	1.372	0.467	0.026	0.014	0.369	0.900	0.273	0.006	0.084	0.005	0.639	0.369
NCH-SW-42-1	6/21/2006	0.210	0.036	0.163	0.141	1.619	0.916	0.017	0.006	0.294	0.859	0.234	0.013	0.075	0.006	0.465	0.338
NCH-SW-43-1	6/20/2006	0.477	0.152	0.476	0.123	2.163	1.332	0.038	0.014	0.123	0.995	0.860	0.062	0.106	0.022	1.124	0.848
NCH-SW-44-1	6/21/2006	0.072	0.026	0.075	0.049	0.124	0.077	0.007	<0.003	0.085	0.124	0.037	0.003	0.010	0.003	0.085	0.085
NCH-SW-45-1	6/21/2006	0.057	0.051	0.084	0.077	0.108	0.091	0.010	0.004	0.413	0.368	0.019	<0.003	0.008	0.003	0.351	0.240
NCH-SW-46-1	6/21/2006	0.207	0.027	0.265	0.096	0.193	0.061	0.014	<0.003	0.076	0.159	0.133	0.003	0.045	0.003	0.393	0.385
NCH-SW-50-1	6/22/2006	0.042	0.016	0.063	0.048	0.322	0.196	0.012	0.006	0.454	0.471	0.031	0.005	0.017	0.003	0.227	0.174
NCH-SW-51-1	6/22/2006	0.034	0.021	0.161	0.129	0.024	0.021	0.005	<0.003	0.023	0.024	0.010	0.005	0.006	0.003	0.030	0.033
NCH-SW-52-1	6/22/2006	0.044	0.017	0.059	0.045	0.325	0.229	0.012	0.004	0.444	0.382	0.030	<0.003	0.019	0.003	0.225	0.109
NCH-SW-53-1	6/22/2006	0.017	0.005	0.051	0.044	0.015	0.006	0.003	<0.003	0.018	0.027	0.009	<0.003	0.005	0.003	0.011	0.013
NCH-SW-54-1	6/22/2006	0.063	0.020	0.092	0.052	0.443	0.274	0.010	0.007	0.464	0.444	0.038	0.005	0.020	0.004	0.234	0.179
NCH-SW-55-1	6/22/2006	0.044	0.027	0.161	0.135	0.033	0.024	0.008	0.003	0.020	0.016	0.002	0.007	0.012	0.006	0.035	0.022
NCH-SW-56-1	6/22/2006	0.038	0.013	0.179	0.123	0.029	0.022	0.004	0.003	0.012	0.020	0.017	0.004	0.008	0.004	0.019	0.022
NCH-SW-57-1	6/22/2006	0.044	0.017	0.061	0.052	0.299	0.201	0.008	0.006	0.365	0.525	0.026	0.005	0.010	0.004	0.147	0.181
NCH-SW-57-2	6/22/2006	0.050	0.015	0.061	0.049	0.300	0.186	0.008	0.006	0.368	0.477	0.029	0.005	0.015	0.004	0.155	0.156
NCH-SW-57-3	6/22/2006	ND	ND	0.020	ND	0.294	0.260	ND	0.010	0.342	0.293	0.020	0.010	ND	ND	0.137	0.120

Table A4: Lower Petes Creek Phase II surface water analytical results

Sample ID	Date collected	V (mg/L)		Cu (mg/L)		As (mg/L)		Se (mg/L)		Mo (mg/L)		Pb (mg/L)		Th (mg/L)		U (mg/L)	
		Total	Diss	Total	Diss	Total	Diss	Total	Diss	Total	Diss	Total	Diss	Total	Diss	Total	Diss
NCH-SW-32-1	6/21/2006	0.015	0.009	0.104	0.099	0.034	0.021	0.007	<0.003	0.065	0.060	0.009	0.004	0.005	0.003	0.068	0.049
NCH-SW-33-1	6/21/2006	0.015	0.015	0.060	0.068	0.049	0.046	0.003	<0.003	0.030	0.030	0.005	<0.003	0.003	0.003	0.027	0.026
NCH-SW-34-1	6/21/2006	0.013	0.008	0.114	0.102	0.073	0.057	0.008	<0.003	0.143	0.129	0.007	<0.003	0.005	0.004	0.122	0.085
NCH-SW-35-1	6/22/2006	0.011	0.008	0.051	0.047	0.037	0.028	0.003	<0.003	0.043	0.046	0.006	<0.003	0.003	0.004	0.029	0.030
NCH-SW-36-1	6/21/2006	0.016	0.015	0.158	0.151	0.016	0.009	0.007	<0.003	0.044	0.037	0.005	<0.003	0.004	0.003	0.071	0.055
NCH-SW-37-1	6/21/2006	0.148	0.010	0.138	0.074	0.358	0.056	0.014	0.005	0.237	0.460	0.107	<0.003	0.040	0.004	0.212	0.178
NCH-SW-38-1	6/21/2006	0.071	0.020	0.107	0.073	0.259	0.175	0.014	0.007	0.276	0.382	0.039	0.004	0.020	0.004	0.147	0.146
NCH-SW-39-1	6/21/2006	0.003	<0.003	0.222	0.205	0.010	<0.003	0.008	<0.003	0.014	0.006	0.005	<0.003	0.004	0.003	0.037	0.027
NCH-SW-40-1	6/21/2006	0.010	0.008	0.102	0.105	0.055	0.051	0.004	0.003	0.194	0.216	0.004	<0.003	0.003	0.003	0.081	0.091
NCH-SW-40-2	6/21/2006	0.011	0.008	0.105	0.099	0.059	0.050	0.004	<0.003	0.212	0.215	0.004	<0.003	0.003	0.003	0.082	0.101
NCH-SW-40-3	6/22/2006	ND	ND	ND	ND	0.056	0.060	ND	0.010	0.202	0.189	ND	ND	ND	ND	0.085	0.073
NCH-SW-47-1	6/22/2006	0.011	0.005	0.014	0.009	0.019	0.008	0.013	<0.003	0.022	0.004	0.008	<0.003	0.006	<0.003	0.005	0.003
NCH-SW-48-1	6/22/2006	0.016	0.017	0.029	0.032	0.042	0.046	0.004	0.004	0.019	0.027	0.006	0.005	0.003	0.004	0.018	0.021
NCH-SW-49-1	6/21/2006	0.021	0.014	0.114	0.101	0.089	0.067	0.007	<0.003	0.087	0.078	0.009	<0.003	0.005	0.003	0.086	0.065
NCH-SW-49-2	6/22/2006	0.020	0.016	0.101	0.108	0.081	0.074	0.004	<0.003	0.073	0.082	0.007	<0.003	0.004	0.003	0.058	0.061
NCH-SW-49-4	6/22/2006	ND	ND	ND	ND	0.086	0.080	ND	ND	0.072	0.061	ND	ND	ND	ND	0.057	0.049